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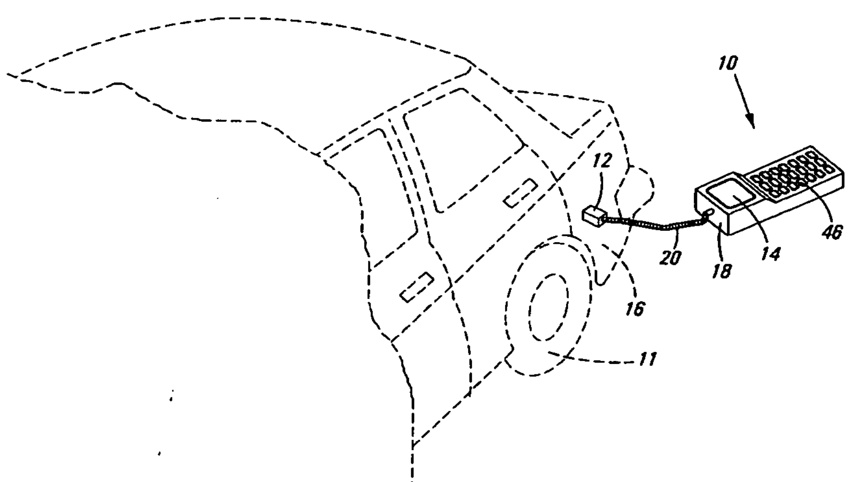
(54) Title: MONITORING OF SHOCK ABSORBERS



(57) **Abstract:** A method of determining the damping factor of a shock absorber includes attaching an accelerometer to one of a first and a second part of the shock absorber. The first- and second parts are displaced relative to one another at least once and the acceleration of the parts relative to each other is measured by reading a signal from the accelerometer. The damping factor is then determined by analysis of the measured acceleration. A shock absorber monitoring system for use in the method includes an accelerometer for generating an acceleration signal. A processor is connected to the accelerometer and reads the acceleration signal from the accelerometer thereby to calculate a damping factor of the shock absorber when the first- and second parts of the shock absorber are displaced relative to one another. An indicator, responsive to the processor, displays a value representative of the damping factor of the shock absorber.

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MONITORING OF SHOCK ABSORBERS

THIS INVENTION relates to the monitoring of shock absorbers, particularly, but not exclusively, for use on, or fitted to, a vehicle suspension.

In accordance with the invention, a method of determining the damping factor of a shock absorber includes

attaching an accelerometer to one of a first and a second part of the shock absorber;

displacing the first- and second parts of the shock absorber relative to one another at least once;

measuring the acceleration of the parts of the shock absorber relative to each other by reading a signal from the accelerometer; and

determining the damping factor of the shock absorber by analysis of the measured acceleration.

Further in accordance with the invention, there is provided a shock absorber monitoring system, which includes

an accelerometer for generating an acceleration signal, the accelerometer being removably attachable to one of a first part and a second part of a shock absorber;

a processor connected to the accelerometer, the processor being operable to read the acceleration signal from the accelerometer and to calculate a damping factor of the

shock absorber when the first- and second parts of the shock absorber are displaced relative to one another; and

an indicator responsive to the processor, operable to display a value representative of the damping factor of the shock absorber.

The shock absorber may be monitored as a unit removed from a vehicle, or it may be monitored while it is fixed to a suspension of a vehicle. The method may then include attaching the accelerometer to a vehicle body which is fast with one of the first part and the second part of the shock absorber, in a position proximate the shock absorber to be monitored, for example, proximate one of the wheels of the vehicle, thereby to determine the damping factor of the shock absorber at the wheel and thereby limiting the effect of the shock absorbers at other wheels of the vehicle.

The accelerometer may include attachment means, to permit removable attachment to the vehicle body, or to one part of the shock absorber. The attachment means may, for example, include a magnetic coupling device, a suction cup, or the like.

The signal from the accelerometer may be read over a period of time, and at discrete intervals, to generate a series of measured acceleration values.

The method of determining the damping factor of the shock absorber may include modeling the movement properties of the shock absorber mathematically with a differential equation, e.g. a second order differential equation, to generate a series of theoretical acceleration values and mathematically fitting the series of theoretical acceleration values to the series of measured acceleration values.

The method may include mathematically solving the differential equation in a time domain, thereby to obtain a theoretical solution to a series of theoretical position values over the period of time.

The method may include mathematically fitting the series of theoretical acceleration values to the series of measured acceleration values in an iterative manner.

The iterative fitting of the series of theoretical acceleration values to the series of measured acceleration values may be repeated until a predefined correlation between the series of theoretical- and measured acceleration values is obtained.

The mathematical fitting of the series of theoretical acceleration values to the series of measured acceleration values may employ a “Nelder Mead” algorithm.

The method may include generating a damping constant from the fitted series of theoretical acceleration values from the mathematical model, thereby to approximate the damping factor of the shock absorber with the damping constant and may include comparing the approximated damping factor of the shock absorber with qualitative data from a manufacturer of the shock absorber.

The method may include generating an alarm when the approximated damping factor falls outside tolerable limits of the qualitative data or if displacement of the parts of the shock absorber is insufficient or excessive.

The method may be repeated a plurality of times and the damping factors thereby obtained may be stored to permit the average of the stored damping factors to be calculated.

Hence, the shock absorber monitoring system may include a storage device to store the damping factors. The storage device, or another storage device, may store a set of instructions, which instructions, when executed by the processor, direct the processor to perform the mathematical calculations as herein described.

The accelerometer may be remote from the processor.

In one embodiment, the shock absorber monitoring system may include an output buffer which is electrically connected to the accelerometer and may include an input buffer, which is electrically connected to the processor. The output buffer and the input buffer may then be connected by means of an electrical cable.

In another embodiment, the accelerometer may include a radio frequency transmitter and the processor may include a radio frequency receiver responsive to the transmitter, operable to receive the acceleration signal by means of a radio frequency signal.

The shock absorber monitoring system may include a power supply, in use to supply electrical power to any one, or more of the accelerometer, the processor and the indicator.

The shock absorber monitoring system may include a communication port connected to the processor, operable to send and receive data to and from a remote device, such as a personal computer.

The invention will now be described, by way of example only, with reference to the following drawings, in which:

Figure 1 shows a three dimensional view of a shock absorber monitoring system in accordance with the invention, in use;

Figure 2 shows a schematic block diagram of a shock absorber monitoring system in accordance with the invention;

Figure 3 shows a graph of a series of acceleration values plotted over time; and

Figure 4 shows a schematic circuit diagram of part of the shock absorber monitoring system of Figure 2.

In the drawings, reference numeral 10 generally indicates a shock absorber monitoring system. The shock absorber monitoring system 10 includes an accelerometer 12, a handheld housing 18 and a coiled electrical cable 20 connecting the accelerometer 12 and the handheld housing 18.

In this example the accelerometer is an ADXL202AE device manufactured by Analog Devices. The accelerometer is a dual-axis accelerometer, of which only one axis is used to determine the damping factor of a vehicle shock absorber.

An indicator 14 in the form of a liquid crystal display (LCD) and a membrane keypad 46 are provided on the handheld housing 18. The shock absorber monitoring

system 10 also includes a buzzer 56 (see Figure 4) which gives audio signals to a user during use of the shock absorber monitoring system 10. The shock absorber monitoring system 10 is used to monitor a suspension (not shown) of a vehicle 16. In use, the accelerometer 12 is mounted proximate a location where the shock absorber (not shown) is installed in the suspension of the vehicle.

The accelerometer 12 has attachment means in the form of a magnetic coupling device (not shown) by which it is removably attached to a metal body of the vehicle 16 so that one of the two axes of the accelerometer is substantially perpendicular to ground level. In another embodiment of the invention, the attachment means may be in the form of a suction cup.

Referring to Figure 2 and to Figure 4, the shock absorber monitoring system 10 is shown in a schematic block diagram and in a schematic circuit diagram. The accelerometer 12 includes a unity gain operational amplifier (not shown). The unity gain operational amplifier of the accelerometer 12 is connected to signal conditioning circuitry 30, by means of the coiled electrical cable 20 of Figure 1. The signal conditioning circuitry 30 is connected to an analog input of a micro processor 32. The signal condition circuitry 30 also includes an operational amplifier wired as a subtractor/amplifier combination and which is tuned to cancel the effect of gravity on the accelerometer and, in addition, to amplify the acceleration signal. The operational amplifiers are both LM358-type devices. The micro processor is a DSP56F827FG80 device available from Motorola.

The shock absorber monitoring system 10 includes a communication interface 38 leading to connector 45. The communication interface is connected to the micro processor 32, and includes an RS232 driver, capable of a data transfer rate of 19200 baud.

The micro processor 32 includes flash random access memory (Flash RAM) 36 for storage of non-volatile data and static random access memory (SRAM) 34 for temporary storage of data and which are schematically shown in Figure 3 but not in Figure 4. The micro processor 32 has the capability to perform mathematical calculations as described below.

The shock absorber monitoring system 10 also includes a battery charger 40, connected to connector 44 and to a rechargeable battery 42. Two parts of the battery charger are shown in Figure 4 by reference numerals 40 and 41. Only a connecter 43 to the battery 42 is shown in Figure 4. The battery charger regulates the supply voltage to the shock absorber monitoring system 10 to 5 volts and provides an electrical supply to charge the battery which is a 7.2V Nickel-Cadmium battery.

The liquid crystal display (LCD) indicator 14 has a graphic display capability and is connected to the micro processor 32. Only the connector and analog control circuitry 15 are shown in Figure 4. The LCD display is a 128x64 dots display from Emerging Display Technologies (EDT) with an 8 bit wide data/address bus interface.

The membrane keypad 46 is connected directly to the micro processor 32 for providing a user interface to the micro processor 32. In use, the micro processor 32

reads the inputs from the keypad 46 as 4 rows and 4 columns connected to 8 digital I/O signals via pull-up resistors (not shown). In Figure 4, only connector 58 to the keypad 46 is shown.

The micro processor 32 has internal processor Flash RAM (not shown) on which executable code, that directs the operation of the micro processor 32, is stored.

The executable code includes commands to read keystrokes from a user via the membrane keypad 46, and includes commands to display information to the user via the indicator 14. Typically the user will be requested to indicate which shock absorber is to be tested (left front, right front, left rear, right rear), the user will also be requested to supply vehicle information, and the results of tests will be displayed on the indicator 14.

In use, the shock absorber monitoring system 10 is switched on and off with a key on the keypad 46, the correct measurement range for the type of shock absorber to be tested is selected on the keypad 46, the accelerometer 12 is attached to the vehicle body 16 and the vehicle body 16 is displaced on its suspension by rapidly pushing down on the body so as to compress the shock absorber in the suspension and then allowing the suspension to settle. As the suspension settles, incidental acceleration values of the vehicle body 16 on the suspension are recorded at discrete time intervals over a period of time, which time is typically the settling period of the suspension. The series of values, when plotted over time, is indicated in the graph in Figure 3 by reference numeral 50.

A formula 54 (see below) providing a theoretical time domain solution to the displacement value of a differential equation is also stored in the processor Flash RAM. With properly selected tuning values the formula 54 will produce a range of displacement values that may produce a graph similar to that indicated by reference numeral 52 in Figure 3. The formula 54 for the time domain solution of the displacement value is as follows:

$$Y = 2\,(1-(PK/2t)(T/t))\,Y_1 - (T^2/t^2 - 2(PK/2t^2)+1)\,Y_0 + K\,(T^2/t^2)\,MV \qquad (54)$$

Where

P = damping constant

K = spring constant

t = lag

T = discrete time interval

MV = initial displacement

Y = displacement at time interval (T)

Y_1 = displacement in previous time interval (T-1)

Y_0 = displacement at time interval (T-2)

Y is differentiated to obtain an acceleration value by the formula:

$$A=d^2y/dt^2 \qquad (60)$$

A range of theoretical values generated by formula 60 is mathematically fitted to the calculated acceleration values by means of a curve fitting algorithm such as the "Nelder Mead" algorithm. The curve fitting algorithm iteratively adjusts the values for P, K and t until the series of Y values approximate the series of measured displacement

values within tolerable limits. It is to be appreciated that any other curve fitting algorithm can be used to fit the range of theoretical displacement values to the calculated range of values. The values for the damping constant (P), the spring constant (K) and the lag (t) are thus determined.

The damping factor (P) is a measure of the effective damping force of the measured shock absorber. Preferably, the procedure is repeated a number of times, e.g. three times, and the average of the best samples presented as a result.

By comparing the damping factor (P) to a previously stored quantitative damping factor from the manufacturer of the shock absorber, the processor 32 calculates whether the damping factor (P) is within tolerable limits of the quantitative damping factor and, if not, generates an alarm.

The result of the calculation is then displayed on the indicator 14. For example, the indicator 14 will display a percentage value of the effectiveness of the shock absorber and will indicate if the shock absorber should be replaced or not. The processor 32 has sufficient memory to store the results of a number of successive shock absorber tests and can download the test results to a PC. The processor 32 is also programmed to give a warning if insufficient or excessive displacement is made to the vehicle during the test.

The Inventor believes that the shock absorber monitoring system 10, as illustrated, provides a system for determining the damping factor of a shock absorber

which is accurate and is easily effected by simply attaching the accelerometer 12 to the vehicle and displacing the vehicle downwardly.

CLAIMS

1. A method of determining the damping factor of a shock absorber which includes

attaching an accelerometer to one of a first and a second part of the shock absorber;

displacing the first- and second parts of the shock absorber relative to one another at least once;

measuring the acceleration of the parts of the shock absorber relative to each other by reading a signal from the accelerometer; and

determining the damping factor of the shock absorber by analysis of the measured acceleration.

2. A method as claimed in claim 1, which includes attaching the accelerometer to a vehicle body proximate one of the wheels of the vehicle body and which is fast with one of the first part and the second part of the shock absorber.

3. A method as claimed in claim 1 or claim 2, in which the signal from the accelerometer is read over a period of time at discrete intervals, to generate a series of measured acceleration values.

4. A method as claimed in claim 3, in which determining the damping factor of the shock absorber includes modeling the movement properties of the shock absorber mathematically with a differential equation to generate a series of theoretical

acceleration values and mathematically fitting the series of theoretical acceleration values to the series of measured acceleration values.

5. A method as claimed in claim 4, in which the differential equation is of the second order.

6. A method as claimed in claim 4 or claim 5, in which the mathematical fitting of the series of theoretical acceleration values to the series of measured acceleration values is performed iteratively.

7. A method as claimed in claim 6, in which the iterative fitting of the series of theoretical acceleration values to the series of measured acceleration values is repeated until a predefined correlation between the series of theoretical- and measured acceleration values is obtained.

8. A method as claimed in claim 7, in which the mathematical fitting of the series of theoretical acceleration values to the series of measured acceleration values employs a "Nelder Mead" algorithm.

9. A method as claimed in claim 8, in which a damping constant from the fitted series of theoretical acceleration values is generated from the mathematical model, thereby to approximate the damping factor of the shock absorber with the damping constant generated from the mathematical model and which includes comparing the approximated damping factor of the shock absorber with qualitative data from a manufacturer of the shock absorber.

10. A method as claimed in claim 9, which includes generating an alarm when the approximated damping factor falls outside tolerable limits of the qualitative data.

11. A method as claimed in claim 9 or claim 10, which includes repeating the method a plurality of times, storing the damping factors thereby obtained, and calculating the average of the stored damping factors.

12. A shock absorber monitoring system, which includes

an accelerometer for generating an acceleration signal, the accelerometer being removably attachable to one of a first part and a second part of a shock absorber;

a processor connected to the accelerometer, the processor being operable to read the acceleration signal from the accelerometer and to calculate a damping factor of the shock absorber when the first- and second parts of the shock absorber are displaced relative to one another; and

an indicator responsive to the processor, operable to display a value representative of the damping factor of the shock absorber.

13. A shock absorber monitoring system as claimed in claim 12, which includes a storage device in which a set of instructions are stored, which instructions, when executed by the processor, direct the processor to perform a set of mathematical calculations.

14. A shock absorber monitoring system as claimed in claim 12 or claim 13, in which the accelerometer is remote from the processor.

15. A shock absorber monitoring system as claimed in claim 14, in which the accelerometer includes a radio frequency transmitter and the processor includes a radio frequency receiver responsive to the transmitter, operable to receive the acceleration signal by means of a radio frequency signal.

16. A shock absorber monitoring system as claimed in any one of claims 12 to 15, which includes a communication port connected to the processor, operable to send and receive data to and from a remote device, such as a personal computer.

17. A method as claimed in claim 1, substantially as described and as illustrated herein.

18. A shock absorber monitoring system as claimed in claim 12, substantially as described and as illustrated herein.

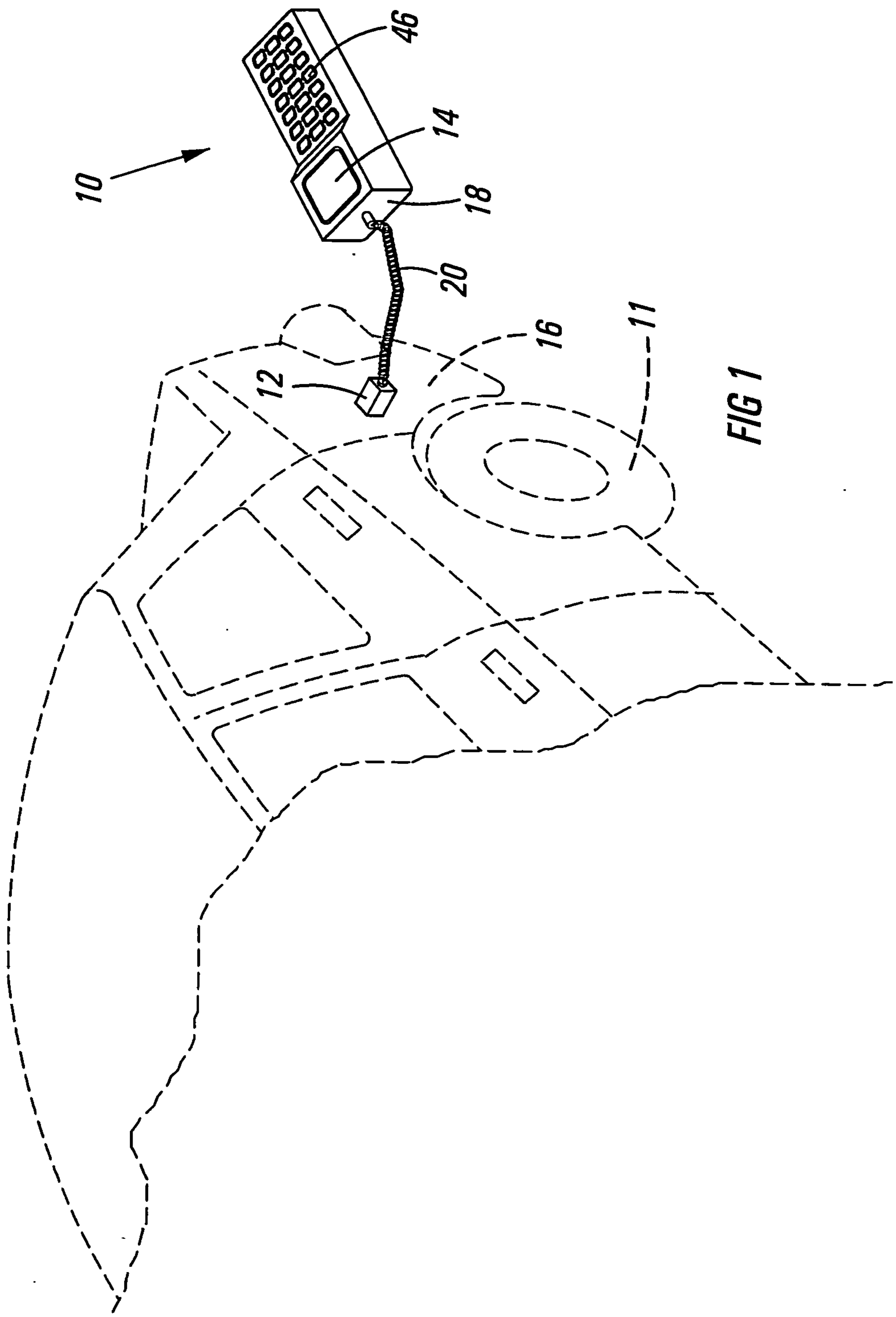

FIG 1

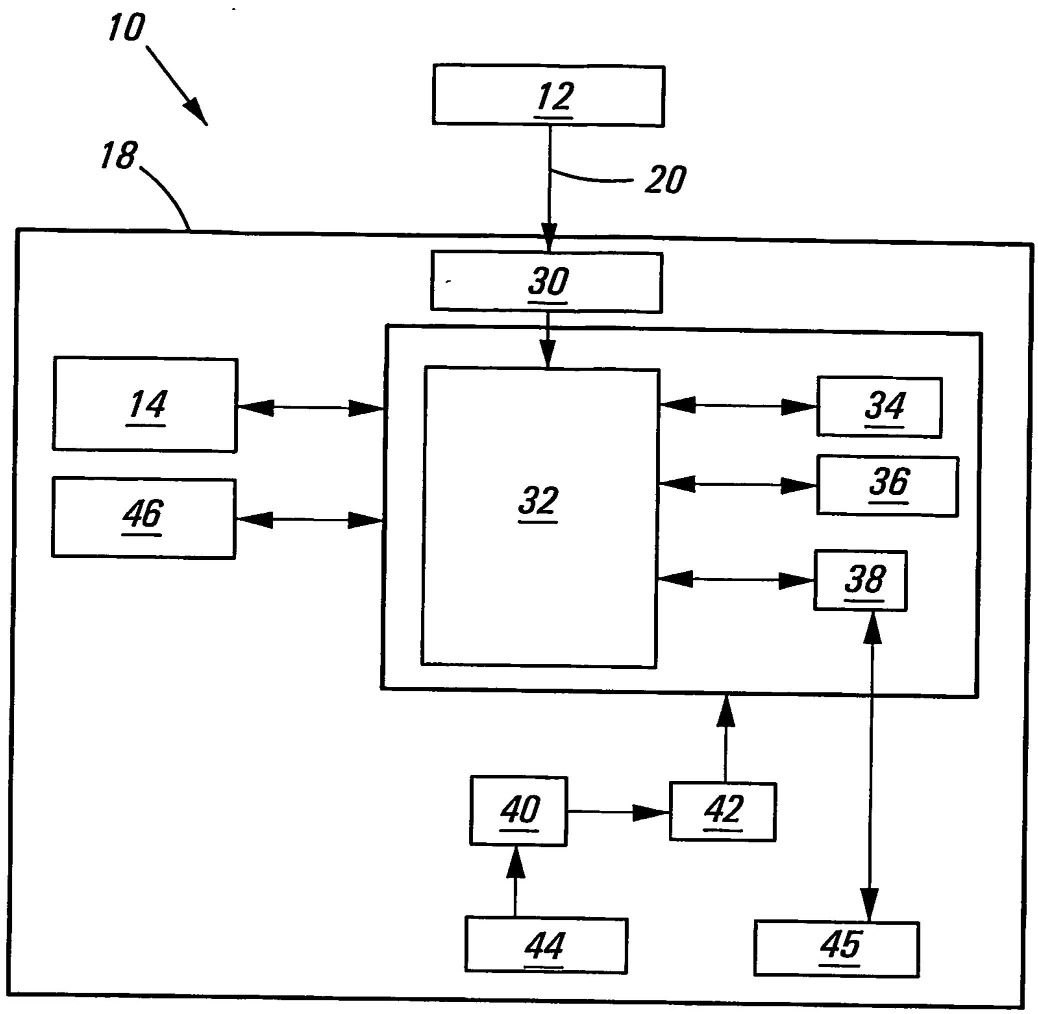

FIG 2

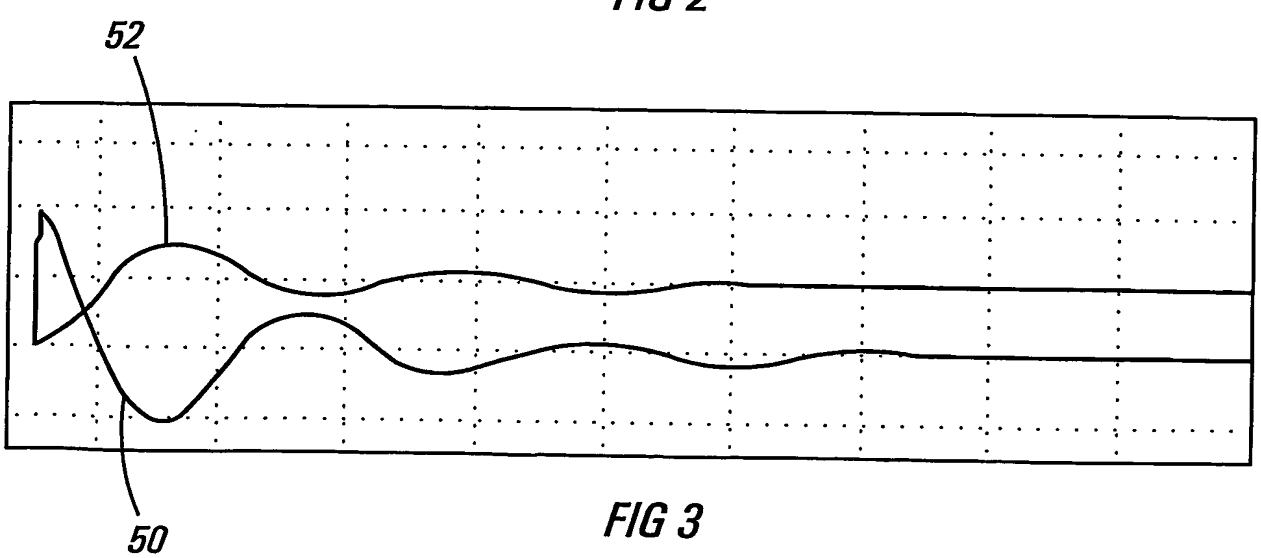

FIG 3

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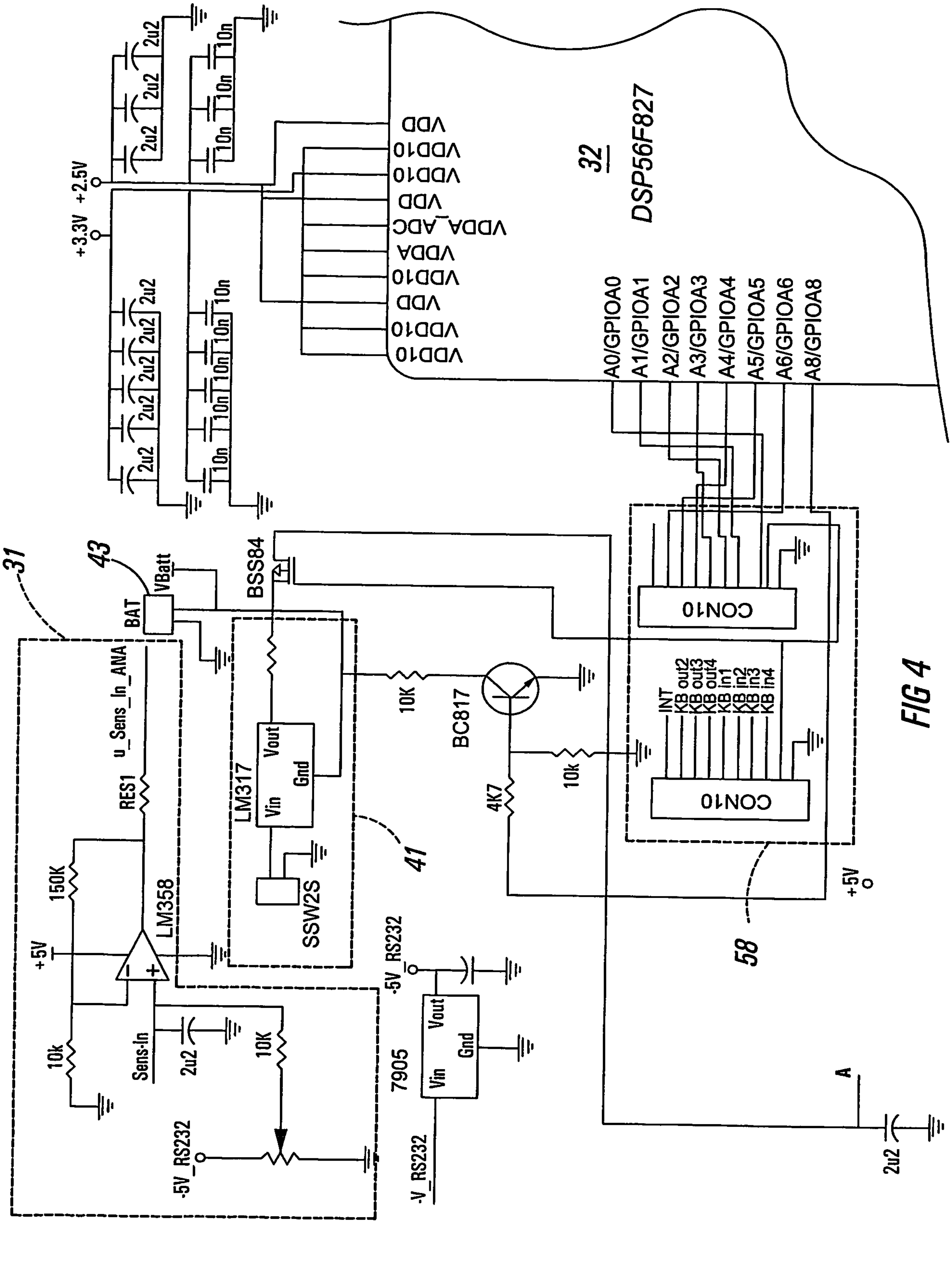
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VDD
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+3.3V
+2.5V
2u2
10n
A0/GPIOA0
A1/GPIOA1
A2/GPIOA2
A3/GPIOA3
A4/GPIOA4
A5/GPIOA5
A6/GPIOA6
A8/GPIOA8
CON10
CON10
INT
KB out2
KB out3
KB out4
KB in1
KB in2
KB in3
KB in4
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+5V
31
43
BAT
VBatt
BSS84
LM317
Vin
Vout
Gnd
SSW2S
41
10K
BC817
10k
4K7
RES1
u_Sens_In_ANA
150K
LM358
+5V
10k
Sens-In
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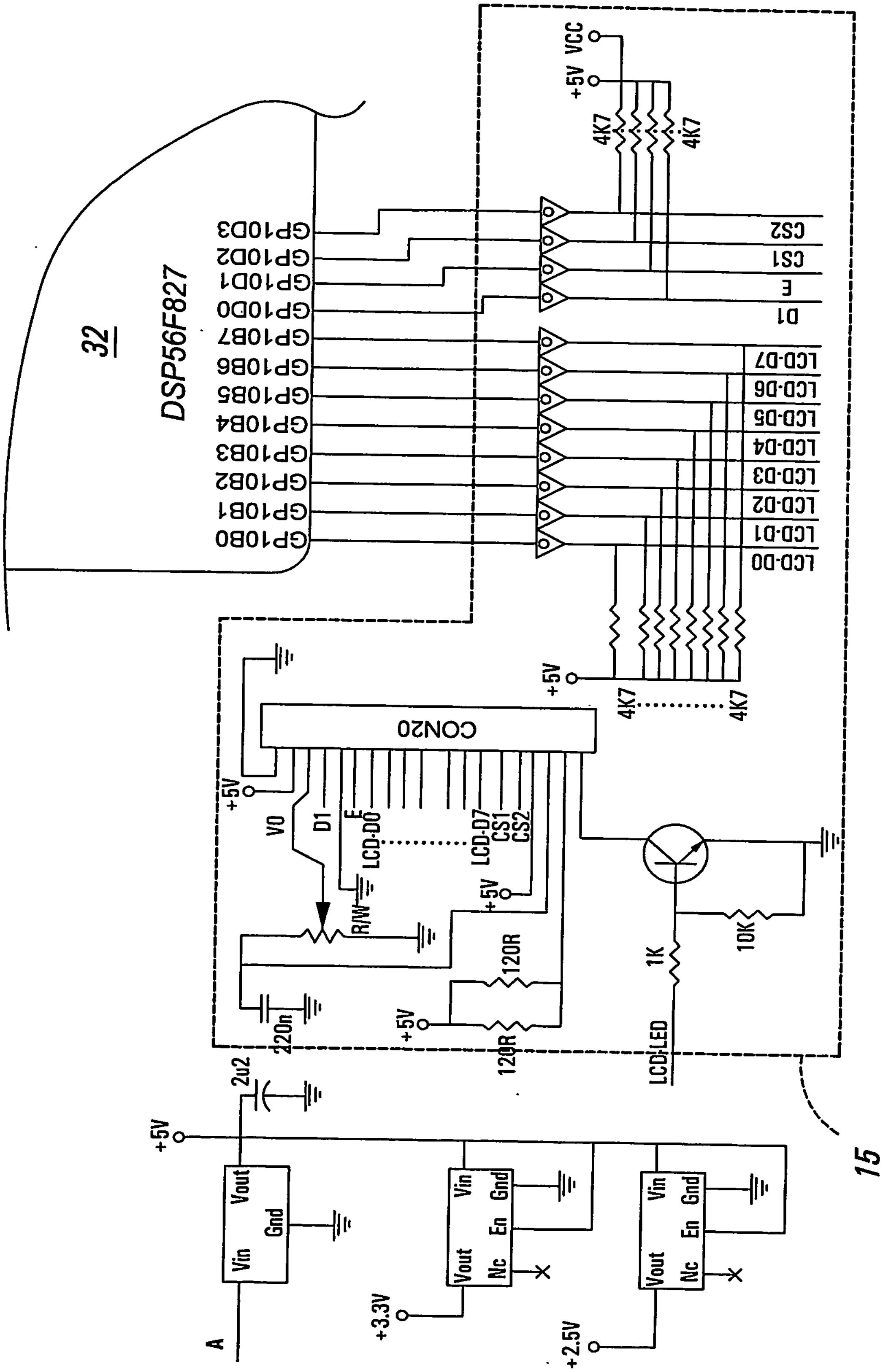
Gnd
-V_RS232
A
2u2

FIG 4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GP10B2
GP10B1
GP10B0
+5V VCC
4K7
4K7
CS2
CS1
E
D1
LCD-D7
LCD-D6
LCD-D5
LCD-D4
LCD-D3
LCD-D2
LCD-D1
LCD-D0
+5V
4K7
4K7
CON20
+5V
V0
D1
E
LCD-D0
LCD-D7
CS1
CS2
R/W
+5V
120R
120R
+5V
220n
1K
10K
LCD-LED
2u2
+5V
Vout
Gnd
Vin
Vin
Gnd
En
Vout
Nc
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Gnd
En
Vout
Nc
A
+3.3V
+2.5V
15

FIG 4(cont.)

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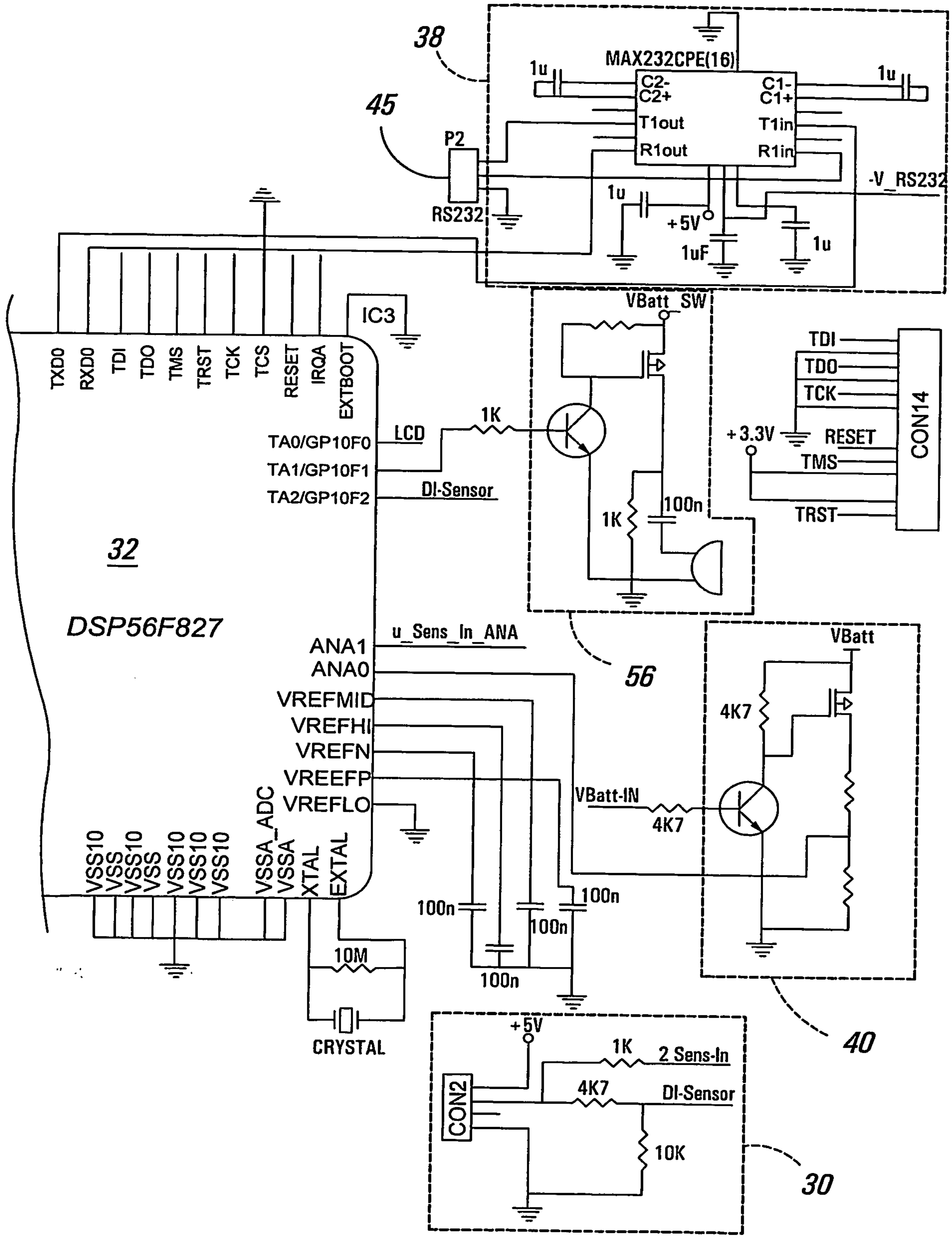
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C1-
C1+
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P2
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-V_RS232
+5V
1uF
VBatt_SW
IC3
TXD0
RXD0
TDI
TDO
TMS
TRST
TCK
TCS
RESET
IRQA
EXTBOOT
TA0/GP10F0
TA1/GP10F1
TA2/GP10F2
LCD
1K
DI-Sensor
100n
TDI
TDO
TCK
+3.3V
RESET
TMS
TRST
CON14
DSP56F827
ANA1
ANA0
u_Sens_In_ANA
VREFMID
VREFHI
VREFN
VREEFP
VREFLO
VBatt
4K7
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VSS10
VSS
VSSA_ADC
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EXTAL
10M
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2 Sens-In
CON2
10K

FIG 4(cont.)

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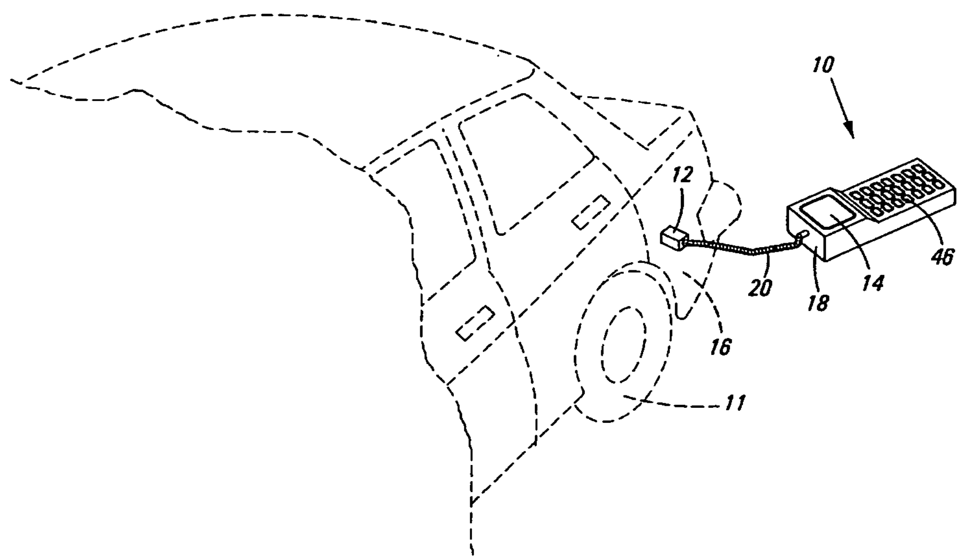

(57) **Abstract:** A method of determining the damping factor of a shock absorber includes attaching an accelerometer (129 to one of a first and a second part of the shock absorber. The first- and second parts are displaced relative to one another at least once and the acceleration of the parts relative to each other is measured by reading a signal from the accelerometer (12). The damping factor is then determined by analysis of the measured acceleration for generating an acceleration signal. A processor (32) is connected to the accelerometer and reads the acceleration signal form the accelerometer thereby to calculate a damping factor of the shock absorber when the first-and second parts of the shock absorber are displaced relative to one another. An indicator (19), responsive to the processor, displays a value representative of the damping factor of the shock absorber.

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PCT/IB 03/05388-0

CLASSIFICATION OF SUBJECT MATTER

IPC[7]: G01M 17/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC[7]: G01M 17/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0355398 A2 (NEEDLEMAN) 28 February 1990 (28.02.1990) *the whole document.*	1-18
Y	EP 0018959 A1 (SINHA) 12 November 1980 (12.11.1980) *the whole document.*	1-18
Y	US 6019495 A (YAMADA) 1 February 2000 (01.02.2000) *the whole document.*	1-18
Y	AU 200071537 A1 (CANON) 17 May 2001 (17.05.2001) *the whole document.*	6,7
Y	JP 59 006306 A (NIPPON STEEL) 13 January 1984 (13.01.1984) (abstract).[online] [retrieved on 23.04.2004]. Retrieved from: Japanese Patent Office PAJ Database. *the whole document.*	8

☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
„A" document defining the general state of the art which is not considered to be of particular relevance
„E" earlier application or patent but published on or after the international filing date
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„X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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„&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 April 2004 (23.04.2004)	23 June 2004 (23.06.2004)
Name and mailing adress of the ISA/AT Austrian Patent Office Dresdner Straße 87, A-1200 Vienna Facsimile No. 1/53424/535	Authorized officer NARDAI F. Telephone No. 1/53424/347

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 03/05388-0

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	ZA 9406337 A (KLEYNHANS) 28 June 1995 (28.06.1995) (abstract).[online] [retrieved on 22.04.2004]. Retrieved from EPO WPI Database DW199535 Accession No.: 1995-269686. *the whole document.*	15

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 03/05388-0

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				ES	T	2035462T	1993-04-16
				DE	D	58902287D	1992-10-22
				AT	T	80727T	1992-10-15
				US	A	4979388	1990-12-25
				EP	A	0355398	1990-02-28
JP	A	59006306 A2				none	
US	A	6019495	2000-02-01	JP	A	6344745	1994-12-20
ZA	A	9406337	1995-03-31			none	